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Study on Risk Assessment of Rainstorm Disaster in Shanxi Province based on GIS

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Abstract: This study focuses on Shanxi Province, establishing an index system for assessing rainstorm disaster risk based on four factors: risk, vulnerability, sensitivity, and disaster prevention capabilities. The evaluation employs the analytic hierarchy process and a weighted comprehensive assessment method. The findings indicate that certain areas in Taiyuan City and Hunyuan County are classified as high-risk zones, while Yangquan City and the western part of Luliang City are deemed medium-risk areas. Most regions in Shuozhou City, Xinzhou City, Changzhi City, Jincheng City, and Jinzhong City fall into the low-risk category.

Keywords: GIS; Shanxi Province; Rainstorm Disaster; Risk Assessment.

1. Introduction

Geographic Information System (GIS) combines real-world geographic information[1], like terrain and buildings, with attribute data such as population and climate for spatial analysis and visualization. In recent decades, secondary disasters like floods and mud-rock flows caused by rainstorms have occurred in many areas.

Takezawa et al proposed a comprehensive disaster risk assessment system[2]. Fekete discusses the quality and acceptance challenges in vulnerability and risk assessment for space hazards[3]. Fischer explores the role of environmental assessment in disaster and risk management[4]. The purpose of this study is to use professional knowledge to further explore the characteristics of Rainstorm disaster in Shanxi Province.

2. Data and Methodology

2.1. Study Area Profile

Shanxi Province, situated in the Loess Plateau, experiences four distinct seasons with significant climatic differences between the north and south. Annual rainfall varies from 358 to 621 mm, with about 60% of precipitation occurring from June to August. Precipitation distribution is heavily influenced by topography.

2.2. Data

In this study, the average number of Rainstorm days and maximum daily precipitation were collected from 107 meteorological observation points in Shanxi Province from 1981 to 2020. Daily precipitation data of 5 meteorological stations. Socio-economic data are derived from official data. In this paper, rainstorm of more than 50 mm for 24 hours is used as the rainstorm standard[5].

2.3. Research Method

General Kriging interpolation is a widely used technique in geostatistics for spatial data interpolation. It operates under the assumption that the data has a constant but unknown mean. By leveraging the spatial correlation among known sample points, it enables effective interpolation of values at unsampled locations.

The Analytic Hierarchy Process (AHP) simplifies complex multi-objective decision-making by dividing the main goal into sub-objectives or criteria. It organizes these into multiple levels, combining qualitative and quantitative measures through a systematic and hierarchical approach.

The weighted comprehensive evaluation method assesses multiple indicators by calculating a composite score based on assigned weights. It transforms qualitative indicators into quantitative data, enhancing objectivity in the evaluation process[6]. This method provides flexible and transparent data support for complex decisions, allowing adjustments in indicators and weights as needed.

3. Rainstorm Disaster Risk Assessment Model in Shanxi Province

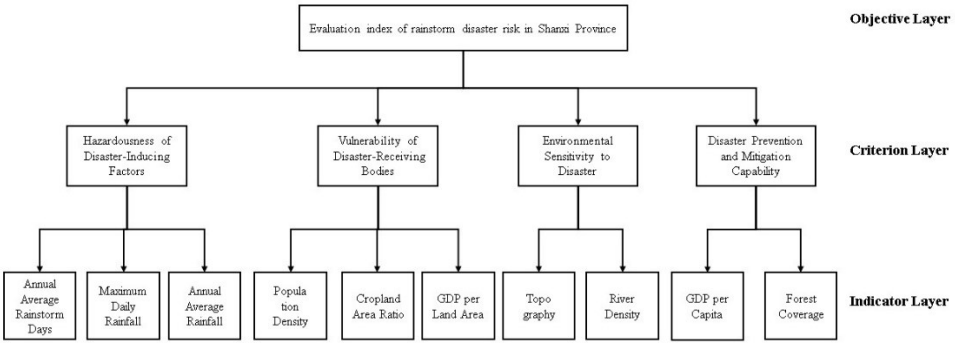

Figure 1. Evaluation index system of rainstorm disaster risk in Shanxi Province

The rainstorm disaster risk system is a complicated system which is easily affected by many factors[7]. According to the actual situation, this study selects the appropriate index to construct the rainstorm disaster risk evaluation index system of this study. See Figure 1.

Systematic testing according to AHP method. Considering the impact of evaluation factors on the formation of rainstorm disaster risk, the weights of relevant indicators were finally obtained, see Table 1.

Table 1. Rainstorm disaster risk index weight table

Primary index	Index weight	Secondary index	Index weight
Hazardousness of Disaster-Inducing Factors	0.35	Annual Average Rainstorm Days	0.30
		Maximum Daily Rainfall	0.16
		Annual Average Rainfall	0.54
Vulnerability of disaster bearing bodies	0.30	Population Density	0.40
		Cropland Area Ratio	0.40
		GDP per Land Area	0.20
Environmental sensitivity to disaster	0.20	Topography	0.67
		River Density	0.33
Disaster prevention and mitigation capacity	0.15	GDP per Capita	0.25
		Forest Coverage	0.75

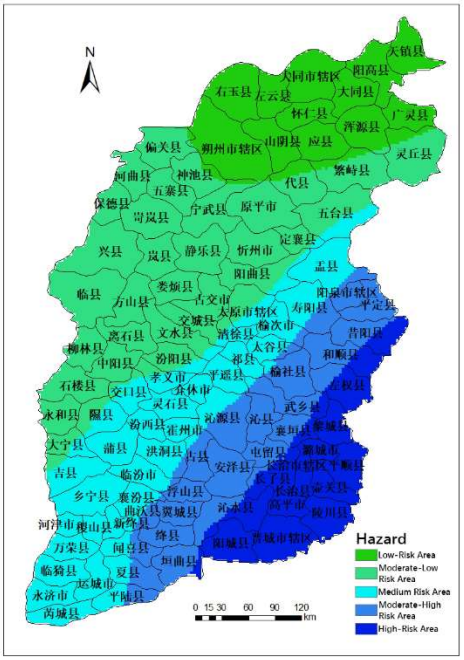

Figure 2. Zoning plan of Hazardousness of Disaster-Inducing Factors

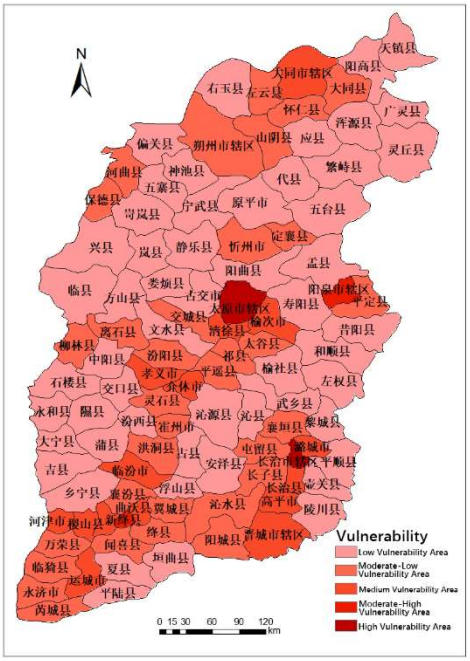

Figure 3. Zoning plan of Vulnerability of Disaster-Receiving Bodies

4.3. Environmental Sensitivity to Disaster

Regional differences in disaster-prone environments influence the context of risk periods and spatial distribution. This is a process characterized by the circulation of matter and the flow of energy.

In this study, river density and topography were chosen as sensitivity factors, and spatial analysis techniques were employed to create a zoning map of environmental sensitivity to disasters. The counties of Northeast Generation, Fansi, and Wutai, along with Guangling, Ying, and Ningwu, exhibit high sensitivity. Conversely, most areas of Yuncheng City in the south have relatively gentle terrain and demonstrate very low sensitivity, see Figure 4.

4. Results

4.1. Hazardousness of Disaster-Inducing Factors

These three raster datasets were combined based on their respective weights to create a raster representation of disaster risk factors, see Figure 2.

In Shanxi Province, the northern and central regions exhibit lower risk levels, while the mid-west and south-central areas are classified as medium-risk zones. The highest risk factors are concentrated in the southeast of Jinzhong City, as well as parts of Zuoquan County, Heshun County, and Xiyang County.

4.2. Vulnerability of Disaster-Receiving Bodies

It includes various social and natural factors such as populations, buildings, property, and the environment. Consequently, the impact of the same disaster-causing factor can differ significantly[8], see Figure 3.

According to the natural breakpoint method, vulnerability is categorized into five levels. Taiyuan, the capital, is classified as highly vulnerable due to its high population density and per-capita GDP. However, Changzhi City, despite a medium population density, has rapidly developed its tourism and improved transportation, resulting in a high vulnerability level. Yangquan City has high population density but is prioritizing resource and environmental protection, leading to industrial transformation. Although its GDP has slightly decreased, it remains highly vulnerable.

4.4. Disaster Prevention and Mitigation Capacity

The capacity for disaster prevention and reduction reflects a region's ability to manage rainstorms and recover from disasters. This capacity is influenced by both the natural environment and economic factors. In this chapter, GDP per capita and forest coverage rate are used as key indicators.

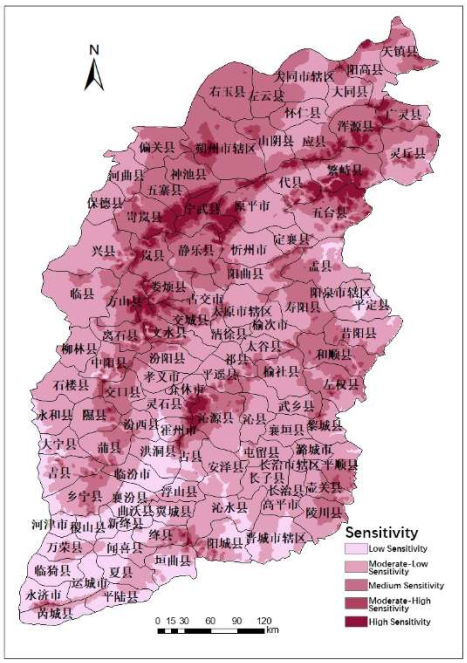

Figure 4. Zoning plan of Environmental Sensitivity to Disaster

Qinyuan County, Xianghuan County, Lucheng City, and Changzhi County demonstrate very high disaster prevention and response capabilities. In contrast, Taiyuan City, despite being the center for disaster prevention and mitigation, shows a gradual decline in its capacity. Overall, the disaster prevention and mitigation abilities in the southeast and northwest regions are superior to those in other areas, see Figure 5.

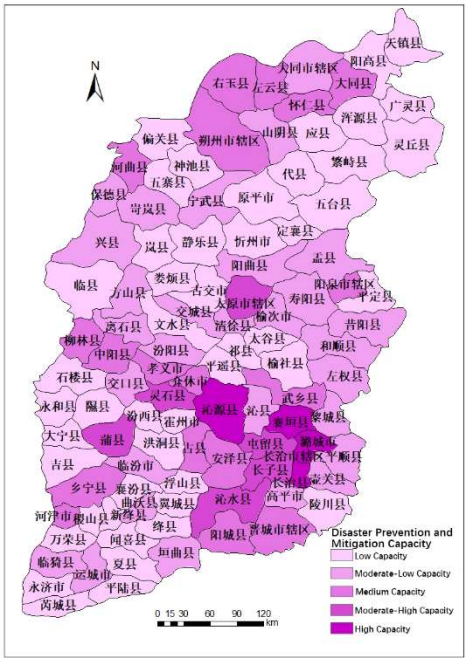

Figure 5. Zoning plan of Disaster Prevention and Mitigation Capacity

5. Conclusion and Discussion

The assessment considered four factors: risk, vulnerability, sensitivity, and disaster prevention and mitigation capacity, with respective weights of 0.35, 0.30, 0.20, and 0.15. The final results serve as a reference for studying rainstorm risk in Shanxi Province, see Figure 6.

(1) High-Risk Area: Taiyuan City is highly vulnerable to rainstorm disasters. Similarly, a small area in central Hunyuan County faces high risk, attributed to its extensive topography, high disaster sensitivity, and limited disaster prevention and mitigation capabilities.

(2) Moderate-High Risk Area: This includes Tianzhen County, the northern edge of Hunyuan County, and Wutai and Fanshi counties in Xinzhou City. The northeastern part of Linxian County, Wenshui County, Xi County, and southern Pingyao County have high topographic sensitivity, low per capita GDP, and weak disaster prevention capabilities. Xinjiang County is particularly vulnerable with low disaster bearing capacity. Lingchuan County in Jincheng has low forest coverage and very weak disaster prevention capabilities.

(3) Medium Risk Area: Yonghe County, Shilou County, Daning County, and the western region of Luliang face limitations in disaster prevention due to economic development. Xixian County and some areas of Yuncheng City have low sensitivity and average disaster preparedness capacity. Gaoping City and Lingchuan County exhibit weak disaster prevention capabilities and low sensitivity. Yangquan City, surrounded by mountains, has high terrain, but its population density, rainfall, and GDP are above average.

(4) Moderate-Low Risk Area: The southern part of Shanxi Province features relatively gentle terrain and lies within the Golden Triangle economic circle of the Yellow River, exhibiting low sensitivity and vulnerability. In Jinzhong City, some districts and counties have moderate disaster prevention and mitigation capabilities, but the high terrain and slow regional economic development contribute to a low vulnerability index.

(5) Low-Risk Area: Huairen, Youyu, and other northern areas experience a temperate continental climate with fewer rainstorms. Their per capita GDP is significantly influenced by population and regional GDP, resulting in strong disaster prevention and mitigation capabilities. In southeastern Changzhi City and most districts of Jincheng City, although Rainstorm days are frequent, sensitivity and vulnerability are low, with high defense capabilities. In the western region, the risk of disaster prevention and reduction is higher, while the risk from the other three factors is lower.

In general, the risk of rainstorm disaster in most counties and cities of Shanxi Province is below the medium risk. Only the provincial capital and a small part of the city are in the higher risk area.

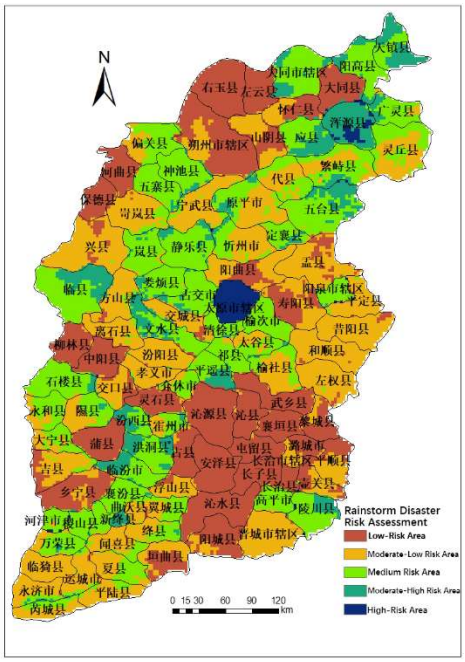

Figure 6. Risk Zoning Map for Heavy Rain Disasters in Shanxi Province

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